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Outline of Iron and Steel Powder Products of JFE Steel[†]

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Abstract:

JFE Steel has contributed to the advancement of powder metallurgy industry, as an only diversified iron powder manufacturer in Japan that can produce both reduced iron powder and atomized steel powder. JFE Steel has a lineup of the product named JIP™ such as pure iron powder, alloyed steel powder and segregation-free powder (JIP™ Cleanmix). These various products have achieved downsizing or dimensional accuracy of the sintered machine parts. Recently, JFE Steel developed products not only for sintered parts, such as "JIP™ JFM™ series" improving machinability of sintered parts and "Ni-free high-strength alloyed powder JIP™ FM series" providing high performance equivalent to 4% Ni partially alloyed powder, but also for other usages including pocket warmers and soil cleanup materials. This paper will review the technology trends of iron powder application, and introduce the current products developed by JFE Steel.

1. Introduction

JFE Steel has contributed to the advancement of various industries, beginning with the powder metallurgy industry, as the only diversified iron powder maker in Japan which produces both reduced iron powder and atomized steel powder[1)].

Reduced iron powder is produced by a process in which iron oxide (mill scale, etc.) and carbonaceous material (coke, etc.) are placed in a container in a layered condition, the iron oxide is reduced by carbon monoxide gas generated by heating, and the reduced iron is then pulverized and heat-treated in a hydrogen atmosphere. On the other hand, atomized steel powder is produced by a process in which molten steel refined in a converter is atomized by blowing a jet of high pressure water on a molten steel flow as it is dropped at a fixed amount from a nozzle; the atomized powder is then dewatered and dried, and the oxide film on its surface is reduced with hydrogen. Fully alloyed steel powders have a uniform alloy component distribution in the powder are produced by adding various types of alloy components to the molten steel in the above-mentioned atomizing process. In partially alloyed steel powder, the alloy component particles are diffusion bonded to the surface of pure iron powder. These powders are produced by mixing iron powder and alloy component powders and heat-treating the mixture in a hydrogen atmosphere.

Since reduced iron powder is porous, has a large specific area and has excellent reactivity, it is used in chemical reaction applications. As advantages when compacting sintered parts, because the die is filled uniformly, deviations in density within sintered parts are small, and the dimensional accuracy of the parts is high. On the other hand, with atomized iron powder, the particles are solid, and it is possible to obtain high density green compacts. For this reason, atomized powders are widely used in high density and high strength sintered parts. In fully alloyed iron powders, the alloy components are uniformly distributed in the particles, which makes it possible to obtain sintered compacts with a homogeneous structure. Because partially alloyed steel powders are based on pure iron powder, they possess excellent compressibility. As a result, high density green compacts can be obtained, and the mechanical strength of the sin-

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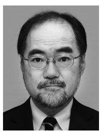
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tered compacts is also high.

JFE Steel has a long history of product development suited to individual applications with all of the types of iron powder having the various features described above. These iron powder products are used in a wide range of fields, beginning with powder metallurgy, under the trade-name JIP™. This paper describes trends in fields using iron powder and presents an outline of JIP products for those trends, together with examples of applications.

2. Industrial Fields Using Iron Powder

2.1 Technical Trends in Powder Metallurgy

Figure 1 shows the transition of Japan's domestic production volume of sintered machine parts, which are the main application of powder metallurgy (PM) products. Production volume showed an increasing trend from 2001, but dropped sharply in 2009 due to the effects of the global financial crisis in 2008, and in spite of a partial recovery since 2010, production has not returned to the former level. **Figure 2** shows the transition of the weight (unit consumption) of PM machine parts used in one automobile in Japan. The weight showed a rising tendency from the 7.3 kg in 2001, increased to 9.7 kg in 2010, but then showed a declining tendency from 2011. This is estimated to be due to the effects of the recent downsizing of passenger vehicles, centering on light automobiles, increase in hybrid vehicles and weight reduction by use of high strength PM machine parts, etc.

Figure 3 shows the component percentages of sintered machine parts in Japan, classified by the parts of vehicles. The percentage of engine parts exceeds 50%; here, cam sprockets, valve guides, valve seats, oil pumps, etc. may be mentioned as applications of PM machine parts. The next highest application is drive train

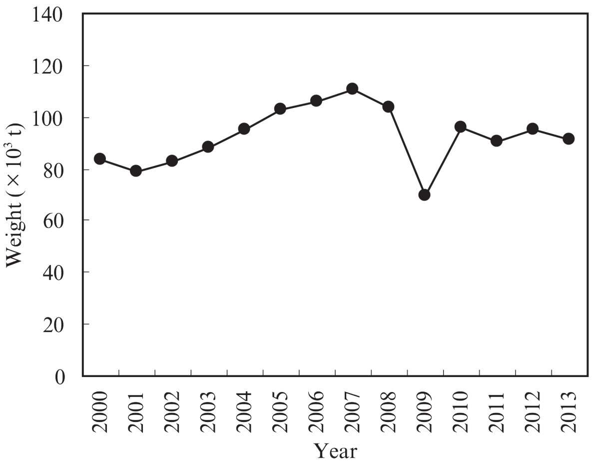

Fig. 1 Domestic production volume trend of powder metallurgy machine parts (Source: Japan Powder Metallurgy Association (JPMA))

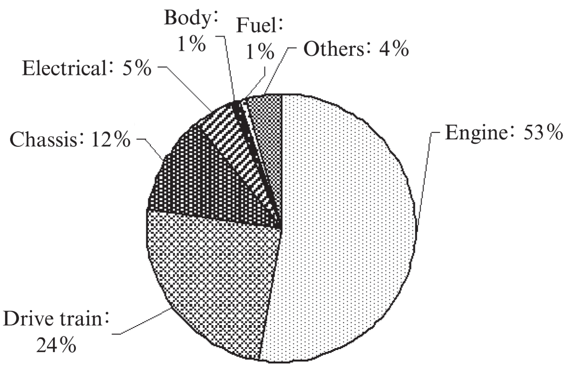

Fig. 3 Component percentages of powder metallurgy parts for vehicle in Japan (2013) (Source: Japan Powder Metallurgy Association (JPMA))

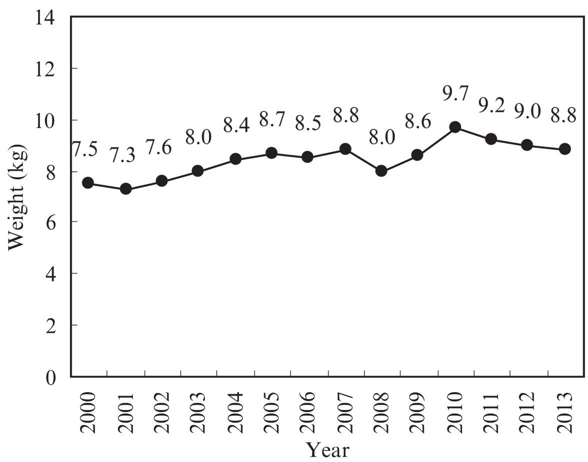

Fig. 2 Trend of total weight of powder metallurgy parts used for one car in Japan (Source: Japan Powder Metallurgy Association (JPMA))

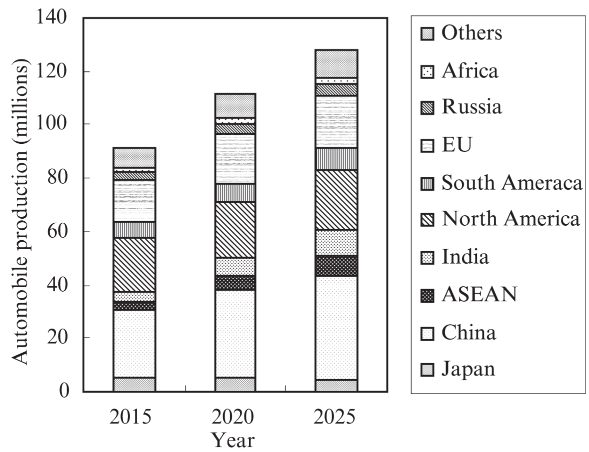

Fig. 4 Global vehicle production over the next ten years (Source: Processing the data in FOURIN, Inc. homepage)

parts, where PM machine parts are used in synchronizer hubs, planetary gears and the like. It is thought that consumption of PM machine parts has tended to decrease due to the increase in hybrid vehicles and engine downsizing of recent years. In the future, application of PM technology to parts other than mechanical parts, beginning with motors, is strongly desired.

The forecast of global vehicle production is shown in **Fig. 4**. As increased production of vehicles is also foreseen in the future, centering on Asia such as China, India, etc., increased demand for iron powder for automotive PM machine parts on the global scale is expected.

2.2 Non-PM Fields of Use

One of non-PM fields of use for iron powder is products in which attention is focused on the reactivity of iron powder. As representative examples, body warmers which utilize heat generation during oxidation of iron powder and deoxidizing agents which use its oxygen-absorbing property may be mentioned.

Iron powder is used as an iron source in chemical reaction applications in the same manner as iron scrap. However, in comparison with iron scrap, iron powder has excellent reactivity and high flowability due to its fine size, and therefore has the advantage of enabling automation of equipment for filling and discharging containers, etc. Because of these advantages, iron powder is used as a raw material for a variety of iron-related compounds. It is also used to recover valuable metals from waste etching solutions.

On the other hand, iron powder is used to improve efficiency and reduce costs in welding work. Iron powder is blended in welding rod covering materials as a supply source for the deposited metal. Welding efficiency is also improved by including iron powder in flux, which makes it possible to increase the welding speed, and also contributes to reducing consumption of welding wire per unit of deposited metal. In another application, iron powder is used to increase the quantity of heat in gas cutting by utilizing the oxidation heat of iron powder.

Focusing on its soft magnetic property, iron powder is used in magnetic parts such as pressed powder cores and sintered cores by applying an insulating coating to the powder surface.

As other uses of the chemical reactivity of iron powder, iron powder products are used to adsorb heavy metal pollutants in soil[2)] and in soil cleanup[3)] by decomposing volatile organic compounds (VOC). In the agricultural field, iron powder is increasingly used to supply iron to agricultural land and is coated on paddy field rice seeds as a weight for direct sowing[4)]. Expansion of these markets is expected in the future.

3. Outline of JIP™ Products

3.1 Outline of JIP™ Products for Powder Metallurgy

JFE Steel has continuously promoted the development of pure iron powders, alloyed steel powders and their segregation-free treatment powders (JIP™ Cleanmix™) as raw materials for use in PM machine parts, thereby contributing to downsizing and weight reduction of automobiles by realizing higher strength in PM machine parts.

Alloyed steel powders are products which were perfected by optimization of the alloy composition and optimization of mass production manufacturing conditions in order to satisfy strength, toughness, wear resistance and other requirements for PM machine parts. In addition to fully alloyed steel powders and partially alloyed steel powders, JFE Steel has also commercialized hybrid alloy steel powders in which alloy component particles are diffusion bonded on the surface of fully alloyed steel powder.

JIP Cleanmix products are premixed powders using pure iron powder (reduced iron powder, atomized iron powder, or mixtures thereof) and the above-mentioned alloyed steel powders are used as the main raw materials. Additive powders (copper powder, graphite powder, etc.) and lubricants are mixed with these main materials in line with the customer's requirements, and additives such as graphite, etc. which have different specific weights are bonded to the iron powder surface by applying JFE Steel's proprietary segregation-free treatment. These products improve the working environment by suppressing scattering of the additives and reducing dust generation at the customer's production line. Moreover, these are high value-added products that contribute to stabilization of the quality of sintered parts because the segregation of the components is minimal and to higher productivity by improving flowability, and also make it possible to add new functions to sintered parts by adding special additives as necessary. At present, JIP Cleanmix is one of the main products in the JIP product line, accounting for more than half of iron powder shipments for powder metallurgy use.

3.1.1 Alloyed steel powders

In order to respond to the needs for higher efficiency and downsizing of automotive parts, which are the main application of iron-based sintered materials, JFE Steel has developed various types of alloyed steel powders for high strength sintered materials.

JFE Steel's Cr type fully alloyed steel powders are Cr-Mo steel powders which are low oxygen, low carbon materials manufactured by a vacuum reduction method and offer excellent compressibility. As high strength and high hardness can be obtained in the as-sintered condition, these materials are suitable for heat resistant and wear resistant parts[5]. The lineup of JFE Steel includes three types, depending on the Cr content: "JIP™ 4100 V" (1%Cr-0.8%Mn-0.3%Mo), "JIP 20CRV" (2%Cr-0.8%Mn-0.2%Mo-0.2%S) and "JIP 30CRV" (3%Cr-0.3%M0–0.3%V).

"JIP SIGMALOY™ 2010" is a 2%Ni-1%Mo partially alloyed steel powder with high compressibility and excellent machinability of sintered compacts[6]. High strength and high wear resistance exceeding those of 4% Ni alloyed steel powder can be obtained by heat treatment after sintering[7].

"JIP 21SX" is an alloyed steel powder in which fine nickel powder, copper powder and graphite powder are bonded to 2%Ni-1%Mo fully alloyed steel powder. By applying a sinter hardening process in which rapid cooling is performed after sintering, high strength and high hardness equal to those of heat-treated materials can be obtained without performing heat treatment of sintered compacts[8,9] Therefore, it is possible to omit carburizing and other additional heat treatment processes, thereby contributing to reduction of sintered part manufacturing costs.

"JIP AH4515" is a Mo hybrid alloyed steel powder[10] in which the equivalent of 0.15% of Mo is diffusion bonded to a 0.45% Mo fully alloyed steel powder. Because the Mo rich region on the partially alloyed steel powder surface forms an α phase with a large diffusion factor at the sintering temperature, sintering proceeds even under the sintering conditions in the mesh belt type sintering furnace, which has a comparatively low sintering temperature, and pores are spheroidized and refined. As a result, high strength equal to that of the high alloy 4% Ni alloyed steel powder can be obtained. In addition, in comparison with the conventional 0.6% Mo fully alloyed steel powder, rotating bending fatigue strength exceeding that of the conventional material can be obtained, as shown in **Fig. 5**, even when the sintering temperature is reduced by 20°C and sintering time is reduced by half, while maintaining the same Mo content[11].

3.1.2 Segregation-free powder "JIP™ Cleanmix™"

(1) "JIP™ Cleanmix™" Contributing to Solving Problems in Compacting

"JIP™ Cleanmix™" was developed to prevent segregation of graphite powder and other additives in premixed powders in which iron powder is the main raw material, and as a measure to prevent dust[12]. Because high density in sintered parts leads to improved mechanical properties, there is a high need for high densification in the compacting process. On the other hand, high densification during compacting increases the green compact ejection force, and appearance defects caused by friction between the die and the compact easily occur. Although metal soap is used as a lubricant to improve sliding with the die, it is desirable to reduce use of this lubricant since it causes contamination in the sintering furnace.

Therefore, JFE Steel developed the segregation-free powder "JIP Cleanmix JWAX"[13] with excellent flowability by using a wax lubricant which contains reduced amount of metal soap. And in response to demands for higher density, the company developed "JIP Cleanmix HDX," [14,15] which enables high densification in room temperature compacting, and for low ejection force, the company developed "JIP Cleanmix LX"[15] which reduces compact ejection force by increasing the lubrication effect by selective concen-

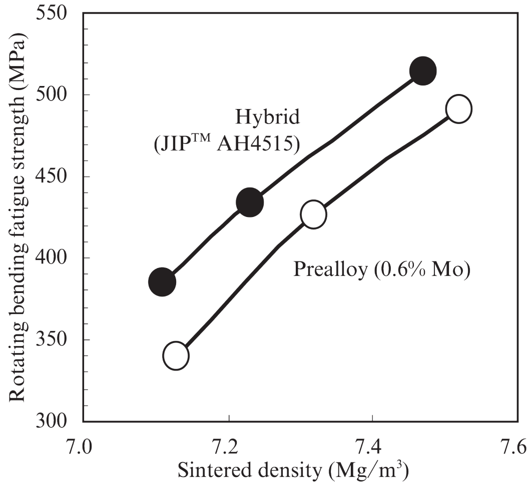

Fig. 5 Rotating bending fatigue strength of the sintered and heat-treated parts

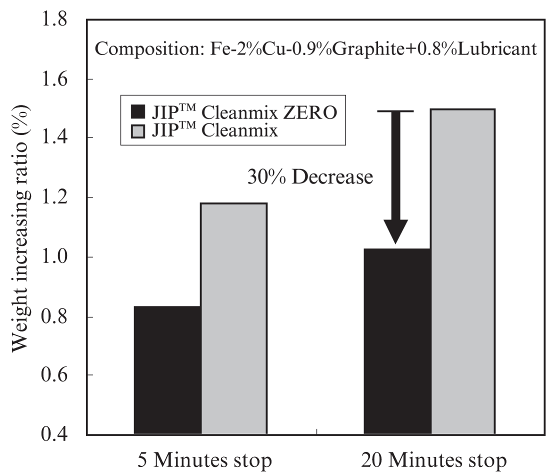

Fig. 6 Weight increasing ratio of green compacts after 5 or 20 min interruption of press machine

tration of a special lubricant on the side faces of the compact. In addition, “JIP Cleanmix ZERO” was developed to reduce weight variations during compacting by improving the filling characteristics of the powder. Thanks to its improved flowability, “JIP Cleanmix ZERO” powder can be filled in the compacting die uniformly with good reproducibility[16), and thus can reduce variations in the weight of compacts during continuous compacting. Discontinuous weight increase, which can be seen when the compacting operation is resumed after a temporary interruption, can also be reduced by 30% in comparison with the conventional Cleanmix, as shown in **Fig. 6**, contributing to improvement of material yield in compacting and stabilization of the quality of sintered parts. Uniform filling characteristics in the compacting die facilitate filling of powders in narrow spaces, making it possible to compact hard-to-form parts with complicated shapes that had been difficult with conventional powders.

(2) Ni-Free High Strength Alloyed Steel Powder Cleanmix™ “JIP™ FM Series”

Because 4% Ni alloyed steel powder has excellent compressibility and enables high densification, it is used as a general-purpose material in high strength PM parts, either as-sintered or with carburization or other heat treatment after sintering, taking advantage of its superior mechanical properties in comparison with other materials[17)].

However, in recent years, the price of Ni raw materials has continued to rise sharply, and a reduction in the use of Ni in sintered parts has been desired. To address this need, JFE Steel developed and commercialized a line of Ni-free high strength alloyed steel powders, the Cleanmix™ “JIP™ FM Series,” with excellent machinability of sintered parts. “JIP FM Series” products satisfy both high strength and reduction of the amount of alloys of sintered parts by control of the sinter structure by adjustment of the blending of the alloying components and mixed powders matched to sintered part production conditions. As this series has a uniform sinter structure with minimal concentration variations in the distribution of alloying elements in comparison with 4%Ni alloyed steel powder, interrupted cutting is reduced and machinability is excellent.

“JIP FM600,” which makes it possible to obtain tensile strength of 600 MPa under the sintering conditions in a mesh belt type sintering furnace, and “JIP FM1000,” which enables tensile strength of 1 000 MPa by performing carburizing heat treatment after sintering in a mesh belt furnace, are Cleanmix products in which copper powder and graphite powder are mixed with 0.45% Mo fully alloyed steel powder, and realized tensile strength equal to that of 4%Ni alloyed steel powder by the effects of Mo, which has a large multiplying factor for steel hardenability, and Cu, which melts during sintering and strengthens particle contact parts (neck parts)[18)].

“JIP FM1300,” which enables tensile strength of 1 300 MPa by performing carburizing after high temperature sintering, is a Cleanmix product in which graphite powder is mixed with the Mo hybrid alloyed steel powder “JIP AH4515. ” During sintering, the Mo-rich region forms an α phase, which has a high mass diffusion rate. As a result, neck parts grow and are strengthened, and simultaneously with this, spheroidizing and refinement of pores are promoted, resulting in sintered parts with high strength and high fatigue strength.

With “JIP FM1500,” tensile strength of 1 500 MPa can be obtained by bright quenching and tempering after high temperature sintering. In this product, Cr, Mn, and Mo, which have large multiplying factors for steel hardenability, are blended with Cleanmix, in which graphite powder is mixed with the 0.5%Cr-0.2%Mn-0.2%Mo fully alloyed steel powder “JIP 5CRA.” [19–21)] Tensile strength of 1 500 MPa is realized by a combination of bright quenching after high temperature sintering in a reducing atmosphere to prevent oxidation[22)].

(3) “JIP™ Cleanmix™ JFM™ Series” for Improved Machinability of Sintered Parts

Although PM products are produced to near-net shape, accompanying the trends toward more complex shapes and higher dimensional accuracy of sintered parts in recent years, machining after sintering has increased and improvement of machinability has been demanded. Conventionally, MnS powder and similar materials were used as additives to improve the machinability of sintered parts, but this resulted in the problems of the dirty surface of the sintered parts, contamination in the sintering furnace, etc. To respond to these problems, JFE Steel developed and commercialized the “JIP™ Cleanmix™ JFM™ Series,” which improves the machinability of sintered parts.

“JIP Cleanmix JFM3” was developed for the purpose of improving the machinability of parts such as the pistons of shock absorbers, in which multiple oil drainage holes are drilled. A special additive in this product is filled in the pores in the sintered compact and eases the impact of intermittent machining, suppressing torque fluctuations during drilling. The size of the drilling chips is also reduced, improving discharge from the system, which contributes to longer drill life[23,24)].

“JIP Cleanmix JFM4” was developed to improve

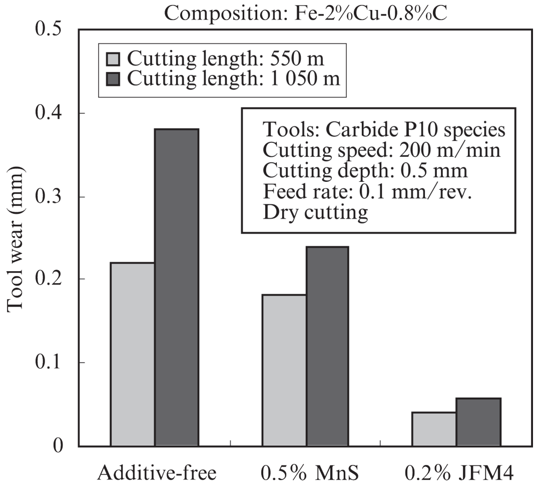

Fig. 7 Effect of the machinability aid on the tool wear

machinability in the turning process and other high speed machining processes. Addition of small amounts of complex oxide powders promotes shearing deformation of chips from the sintered compact, resulting in refinement of the chip size, and the complex oxides soften under frictional heat during processing, adhere and spread on the tool, and thus form a protective film on the tool surface by way of the chips[25–27]. As shown in **Fig. 7**, the amount of tool wear is reduced to 1/4 or less of that with additive-free material and 1/3 or less of that with 0.5% MnS added material. Since the effect of reducing tool wear is large in high speed machining, in which tool wear normally increases, this product can contribute to reducing tool costs and improving productivity in machining processes.

With “JIP Cleanmix JFMX,” a machinability improvement effect can be obtained over a wide range of cutting speeds. This product is suitable for improving the machinability of sintered parts which are processed by different processing methods or at different cutting speeds, for example, in improvement of accuracy by turning and in drilling holes, etc. An extensibility additive promotes shearing deformation and refinement of chips by leaving the pores formed during plastic deformation accompanying machining, and complex oxides reduce tool wear by forming a protective film on the tool[28,29]. The synergistic effect of these improvements realizes excellent machinability independent of the processing conditions.

3.2 Outline of Non-PM JIP^{TM} Products

3.2.1 Premixed iron powder for seed coating “Kona-Bijin^{TM}” [4]

In recent years, direct planting techniques for wet-culture rice by Fe coating have attracted attention from the viewpoints of cost reduction and labor saving in rice cultivation. Fe-coating direct planting of paddy rice is a cultivation method in which rice seeds coated with iron powder are sown directly in the paddy field and germinated, established and grown in the paddy. Because this eliminates the need for seedling raising work, seedling transportation and transplantation (rice planting), large labor savings are possible in comparison with the wet sowing/transplantation cultivation method now used in Japan.

With iron powder for seed coating “JIP^{TM} S91,” it is possible to maintain high adhesion with the seeds after drying because the size of the iron particles is reduced in comparison with JFE Steel’s existing iron powders. This suppresses dust generation due to iron powder separating from the seeds, and thus also contributes to improvement of the working environment. “Kona-Bijin^{TM}” is a premixed iron powder for use in seed coating, in which JIP S91, which functions as a weight, and calcined plaster as an adhesive are mixed uniformly at a specified ratio. As the iron powder and plaster are mixed in advance, weighing and mixing work by the farmer are simplified, further contributing to labor saving.

3.2.2 Iron powders for body warmers

Among pure iron powders, reduced iron powder has the advantage of a large specific area and thus is suitable for exothermic reaction (heat generation by oxidation). For this reason, reduced iron powder is widely used as an iron powder for body warmers. In the JIP^{TM} product line, JFE Steel has developed iron powders for body warmers in response to customers’ requests based on JIP K-100T using mill scale as the raw material and JIP KB-90, using iron ore.

3.2.3 Iron powders for environmental applications (soil cleanup)

Heightened concern about environmental problems, strengthening of legal regulations (Japan’s Soil Contamination Countermeasures Act) and similar trends have further increased the necessity of responding to soil contamination. In answer to demand for iron powders for applications such as adsorption of toxic heavy metals contained in soil and soil cleanup by decomposition of volatile organic compounds (VOC), etc., JFE Steel provides various particle sizes and types (reduced iron powder, atomized iron powder) of base iron powders for environmental applications which reduce harmful impurities and are suitable for use in treatment, thereby responding to the requests of customers.

4. Conclusion

The fields of use of iron powder span a diverse range. JFE Steel has developed iron powder products for a wide variety of applications and is developing those products in markets. The company has received ISO 9001 and ISO 14001 certification for its JIP™ products and has established a system which makes it possible to supply environment-friendly products with stable quality. JFE Steel will continue to promote product development in line with the needs of society and technical trends in respective fields, and will contribute to the progress of industry in various aspects, such as energy saving and environmental countermeasures, by supplying those products to the market.

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